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A CALCULATION OF ν -DISTRIBUTIONS IN
HADRON-NUCLEUS INTERACTIONS.

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A Calculation of ν -distributions in Hadron-Nucleus
Interactions.

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Abstract:

The probabilities $\Pi(\nu)$ for an incoming hadron to hit ν nucleons in a nuclear target are calculated by a Monte-Carlo technique where generated nuclei are bombarded with a randomly generated hadron beam.

A Collection of Mathematical Problems in Modern Physics

Introduction

1. The Atom

2. The Molecule

Department of Theoretical Physics

University of Leiden, Leiden, Holland

1927

and

1928

1929

1930

1931

1932



1933

1934

The following problems are intended for the use of students in the Department of Theoretical Physics, University of Leiden, Holland. They are arranged in order of increasing difficulty, and are intended to be used as a guide for the study of modern physics.

Most models dealing with hadron-nucleus collisions [1-5] uses the interpretation that the incoming hadron interacts primarily with a certain number of nucleons, v , in its way through the nucleus. The average value of v is usually defined as [6]

$$\langle v \rangle = \frac{A\sigma_{hN,inel}}{\sigma_{hA,inel}} \quad (1)$$

which implies that the inelastic hadron-nucleon cross section is the same throughout the projectile trajectory. If the v -distributions $\Pi(v)$ is known one has a possibility to further improve and test these models.

In this paper we present calculations of the v -distributions where we use randomly generated nuclei with the mean thickness according to eq. 1 (i.e. the inelastic cross sections are given by experiment). The method relies purely on classical physics and is similar to the probability calculus performed in ref. [1] and [2]. We believe, however, that our method is more realistic since we have a criterion for the individual nucleons to stay apart from each other (see below). There are also other advantages with our approach. One might trace each individual nucleon, and thereby eventually be able to get information on the recoil nucleons [7]. Another advantage is that it is easy to modify e.g. if one wants to calculate the v -distributions with a non-constant cross-section for the projectile (after the first collision the excited projectile might have a larger cross-section).

The generation of a target nucleus has been done in the following way:

We use a Wood-Saxon form for the nuclear density, which gives the probability of finding a nucleon at a distance r from the center of the nucleus,

$$P(r)dr = \frac{K}{1 + \exp\left(\frac{r - r_0 A^{1/3}}{c_0}\right)} dr \quad (2)$$

where K is a normalization constant such that

$$A = \int_0^{\infty} P(r) dr \quad (3)$$

The constant c_0 is chosen to be .545 fm (skinthickness $t = 2 c_0 \ln 9 = 2.4$ fm), while r_0 is chosen to fit the experimental nuclear inelastic cross section, which means that r_0 depends on the mass number A .

The nucleons are generated with r -values from the above given distribution (eq. 2) and a position is then determined by two generated angles. As soon as the distance between two generated nucleons is less than $r_{\min}$ (we do not allow two nucleons to occupy the same place), the last generated particle will obtain a new set of angles. If the radius is small and there is no space available a new radius is generated. The distance $r_{\min}$ is chosen such that $\pi r_{\min}^2 = 40$ mb. When all A nucleons are generated we have a nucleus, where the positions of the nucleons are fixed (i.e. the motion inside the nucleus is neglected). This is justified by the fact that the velocity of the incoming hadron is much larger than those of the nucleons inside the nucleus.

Such generated nuclei are now bombarded with a randomly generated hadron beam, covering all parts of the nucleus where

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a nucleon might be located. With an inelastic hadron-nucleon cross section $\sigma_{hN,inel}$, we define that a hN scattering has occurred as soon as the distance between the hadron and one of the nucleons is less than

$$r_{sc} = \sqrt{\frac{\sigma_{hN,inel}}{\pi}} \quad (4)$$

Now we are ready to calculate the v -distribution. As soon as a hadron interacts with the nucleus, the number of hit nucleons are counted.

The method described above will automatically satisfy the conditions for eq. 1 since the "nuclear volume" $A \cdot \sigma_{hN} \cdot 1$ is given by $1 \cdot \sigma_{hA} \cdot \langle v \rangle$.

We have performed the calculations with both protons and pions as incoming hadrons. The resulting distributions for some different targets are presented in tables I and II. We also give the r_0 -values that are determined by the requirement that our calculated total inelastic cross-section should be the same as the experimental values given in ref. [8].

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Table I.

ν -distributions for proton-A collisions. $\sigma_{pN,inel} = 32$ mb.
CNO and AgBr corresponds to the light and heavy
components of nuclear emulsion.

A	C 12	Al 27	Cu 64	Ag 108	Pb 207	CNO 14	AgBr 94
r_O	0.64	0.86	1.01	1.06	1.12	0.68	1.04
ν	$\Pi(\nu)$						
1	.5771	.4462	.3387	.2835	.2247	.5457	.2959
2	.2565	.2445	.2105	.1818	.1481	.2548	.1885
3	.1159	.1599	.1670	.1572	.1342	.1303	.1673
4	.0397	.0919	.1291	.1357	.1328	.0515	.1344
5	.0095	.0406	.0849	.1082	.1211	.0146	.1044
6	.0013	.0132	.0441	.0715	.0984	.0028	.0653
7	.0001	.0032	.0180	.0380	.0700	.0003	.0336
8		.0005	.0059	.0161	.0394		.0144
9		.0001	.0014	.0057	.0198		.0046
10			.0003	.0018	.0077		.0012
11			.0001	.0004	.0028		.0003
12				.0001	.0008		
13					.0002		
$\langle \nu \rangle$	1.65	2.09	2.66	3.10	3.75	1.74	3.00

Table II.

ν -distributions for pion-A collisions. $\sigma_{\pi N,inel} = 21$ mb.

A	C 12	Al 27	Cu 64	Ag 108	Pb 207	CNO 14	AgBr 94
r_O	0.54	0.77	0.92	1.00	1.07	0.57	0.97
ν	$\Pi(\nu)$						
1	.6622	.5226	.4021	.3447	.2789	.6303	.3536
2	.2471	.2709	.2527	.2347	.2030	.2549	.2367
3	.0746	.1391	.1801	.1863	.1813	.0908	.1867
4	.0144	.0524	.1054	.1282	.1503	.0212	.1261
5	.0016	.0128	.0434	.0680	.1002	.0026	.0643
6	.0001	.0021	.0131	.0277	.0536	.0002	.0242
7		.0002	.0027	.0082	.0227		.0067
8			.0003	.0019	.0077		.0014
9				.0003	.0017		.0002
10					.0005		
11					.0001		
$\langle \nu \rangle$	1.45	1.77	2.19	2.47	2.90	1.51	2.42

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